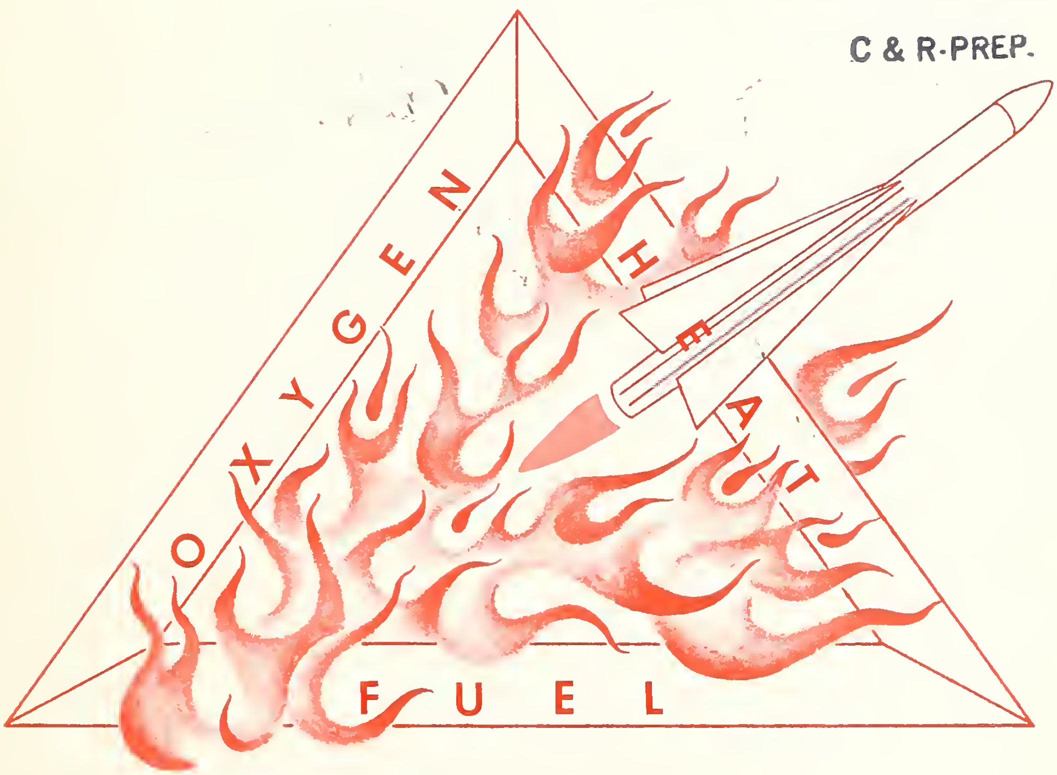
INTRODUCTION TO THE FUNDAMENTALS OF FIRE BEHAVIOR

Programed Learning

A Powerful New Training Tool



FOREST SERVICE, DEPARTMENT OF AGRICULTURE

Under the technical direction of the Division of Fire Control, U.S. FOREST SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE

Programed Learning

A Powerful New Training Tool

INTRODUCTION TO THE FUNDAMENTALS OF FIRE BEHAVIOR

Produced under the technical direction of the Division of Fire Control, Forest Service, U.S. Department of Agriculture in cooperation with Training Systems, Inc., 12248 Santa Monica Blvd., Los Angeles, Calif., 91125.

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U.S.

For sale by the Superintendent of Documents, Government Printing Office
Washington, D.C., 20402 - Price 45 cents

INTRODUCTION TO FUNDAMENTALS OF FIRE BEHAVIOR

This introductory course is designed to teach you, the fireman, fundamental fire behavior terms and concepts. This is important to you because successful firefighting is based on a knowledge of fire behavior. Why does a fire burn fast? Why does it slow down? Why does it burn intensely at times? Why does it burn faster in one direction than another? You must know the answers to questions such as these to be an effective firefighter.

There are many reasons for fires acting as they do. When you finish this course you will know the primary factors which influence the start and spread of fire. You will learn about combustion, the fire triangle, heat transfer, and how weather, fuel, and terrain affect fire behavior. Keep in mind, however, this is only a beginning course; it needs to be followed with additional fire behavior training.

The information presented here makes use of a powerful new training approach, programed learning. Small amounts of information are presented in logical sequence and you will make frequent written responses.

It will take you about 1½ to 2 hours to complete this course. Before starting, keep in mind the definition of fire behavior, "the manner in which fuel ignites, flame develops, and fire spreads."

Merle S. Lowden
Director, Division Fire Control
U.S. Forest Service

HOW TO USE THIS BOOK

This is a programed course which allows each person to learn at his own individual rate. It is presented in a series of small steps called "Frames." Each frame will present information and ask a question. The answer to the question will appear on the next page.

1. To use this book, read the information and question, and look at the illustration.

2. Write your answer to the question on the answer sheet or on a different piece of paper. Your answer must be written. If there is a blank, write the missing word. If you are asked to make a choice of several answers, write the letter of your choice. Follow all instructions in answering the questions.

3. After you have written your answer, turn the page to reveal the correct answer in the shaded portion of the next page.

4. Compare your answer with the correct answer.

5. Now continue with the next frame.

6. There are five frames per page. Read through the top frames of each page, then through to second row of frames and continue until you finish the bottom row of frames.

7. Each frame is numbered. The correct answer to the frame (on the next next page) bears the same number. To be sure that you are reading the frames in the proper order, start with Frame 1 and continue to Frames 2, 3, 4, etc., until the course is complete.

A Summarized Reference is provided at the end of this course. It may be readily referred to as a review when you have completed the course.

CONTENTS

1

INTRODUCTION TO THE FUNDAMENTALS OF FIRE BEHAVIOR

GO TO NEXT FRAME

32

ignition

33

(a) IGNITION TEMPERATURE is the temperature of a ________ at which it just starts to ________ and continues without ________ from an outside source.

(b) Forest fuels have ______________ ignition temperatures.

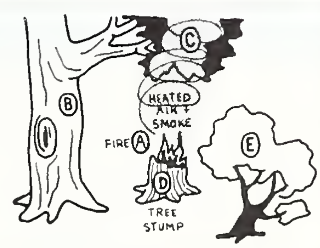
64

(a) radiation
(b) convection
(c) conduction

65

Here is a tree stump on fire. See if you can tell the method of transferring heat.

Heat is transferred from the fire Ⓐ .
Heat received at Ⓑ is by __________,
the heat at Ⓒ is by ______________,
the heat at Ⓓ is by ______________,
and heat at Ⓔ is by ______________.

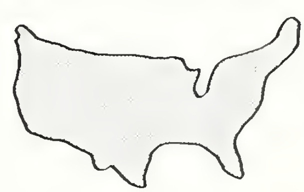


96

moist (or wet)
water (or moisture)

97

Relative humidity at any location in the United States will depend upon several different causes. It is agreed that readings of 30% down to 0% are dangerous. The amount of danger will depend upon the conditions at the actual location.



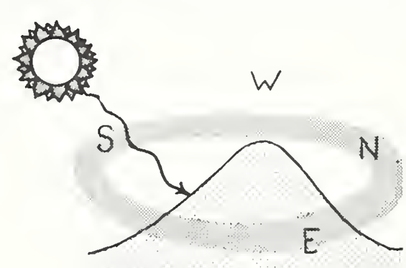
GO TO NEXT FRAME

128

side
slope

129

The southwest exposures receive most of the sun during the year. The exposure which receives the least amount of sun is the ____________, which is directly opposite the southwest.



1

2

The ACT OF BURNING is called COMBUSTION.

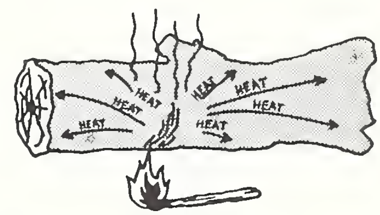
Fuel, oxygen and heat are needed to start a fire and maintain ________________.

33

(a) fuel
burn
heat
(b) different

34

This small log is heated with a match. While the flame is hot, the heat from the match is absorbed by the small log and carried away. As a result, the match will go out before the small log burns.



GO TO NEXT FRAME

65

Ⓑ radiation
Ⓒ convection
Ⓓ conduction
Ⓔ radiation

66

WEATHER FACTORS

Now we will study "Weather Factors" in our INTRODUCTION TO THE FUNDAMENTALS OF FIRE BEHAVIOR.

This will consist of

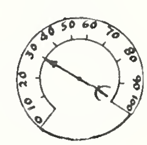
. . . . WIND . . . . TEMPERATURE . . . . HUMIDITY

GO TO NEXT FRAME

97

98

A relative humidity of 30% or below would be considered ____________ for the Forest Service, because it has too ________ moisture.

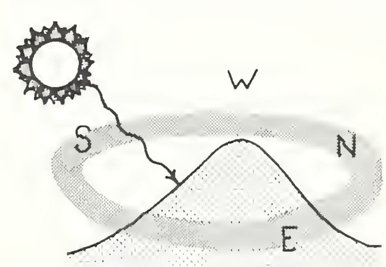


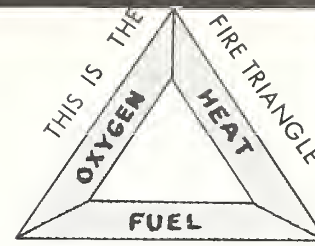
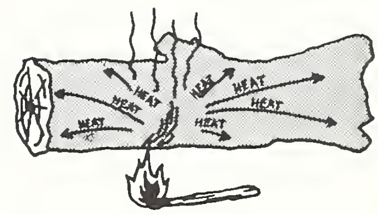
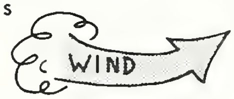
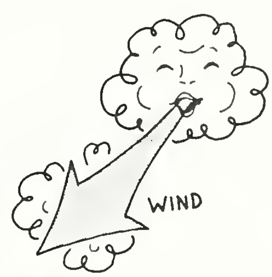
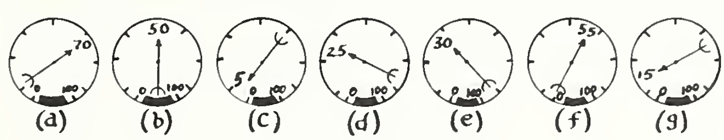
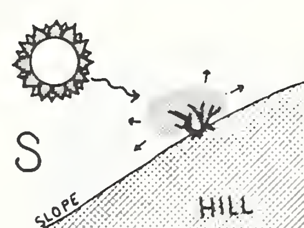
129

northeast

130

The most hazardous exposure is the one receiving the most sun, since it also receives the most heat. This is the ______________ exposure.



2	3 **THE FIRE TRIANGLE**
combustion	In order to have COMBUSTION, ________, __________ and ________ are needed. 
34	35 The small log is heated with a match. CIRCLE ONE (a) the log will burst into flame. (b) the log will burn for a few moments with a good flame and then be extinguished. (c) the log will not burn because the match loses all of its heat in the air. (d) the log will not burn since the heat will be absorbed along the log. 
66	67 Of all the things making up weather, the one which changes most often and most quickly is   GO TO NEXT FRAME
98 dangerous little	99 Here are relative humidity readings. Circle the ones considered dangerous for fire conditions. 
130 southwestern	131 The heat from the sun raises the temperature of the ground and aerial fuel. This heat reduces the ________ in the fuel, which then evaporates into the air. 

725-565 O-64—2

3

FUEL
OXYGEN
HEAT

4

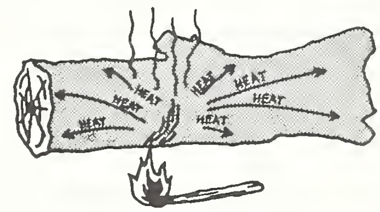
Here is a diagram marked FUEL. Substances which burn are called ________.

35

ⓓ is the correct answer.

36

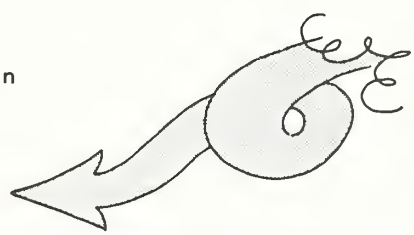
This match will not produce enough heat to cause the small log to ______. There isn't enough heat to bring the log up to its ________ ____________.



67

68

The thing which changes most in weather is the _________.



99

ⓒ ⓓ ⓔ ⓖ

Remember: below 30% relative humidity is dangerous in wooded areas.

100

(a) Forest fuels when heated lose ______________.

(b) Water vapor in air is also called ______________.

(c) Air with little water vapor is _____ air.

(d) Dry air has a ______ relative humidity.

131

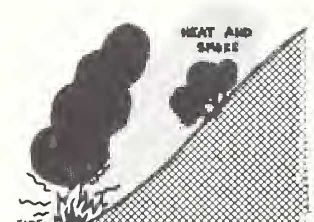
moisture

132

In the Forest Service, there is a rule which states

FIRE BURNS FASTEST UPHILL

In fact, on a steep slope it burns uphill 16 times faster than downhill.



GO TO NEXT FRAME

4

FUEL

5

It is never possible to have combustion without fuel.

What do we call substances which burn?

Answer this question by printing in here ⟶

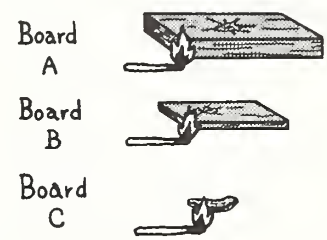
36

burn
ignition temperature

37

Here are three wooden boards. The same heat is applied for the same time.

Board ____ will probably combust and continue to burn without any ________ from another source.

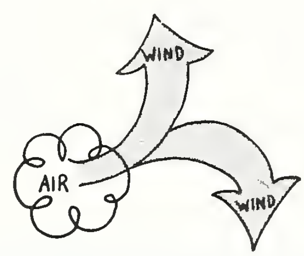


68

wind

69

You may think of WIND as a movement of air. This ____________ of _____ may be in any direction, UP DOWN or SIDEWAYS.



100

(a) moisture
(b) moisture
(c) dry
(d) low (or small)

101

(a) Dangerous conditions exist in wooded areas when relative humidity is below ______%.

(b) Air is actually _____ when the relative humidity is 95%.

132

133

Think about the remarkable speed of fire uphill. It burns 16 times faster going up the slope than if it burned down the slope.

Can you think of the two main reasons for this? Write:

____

____

5

6

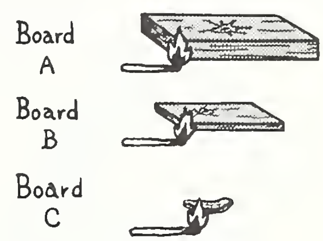
In order to have combustion, we have learned that one thing we must have is ____(print)____

37

C
heat

38

Board ____ will probably not burn because the ________ from the match will be carried away due to the size of the board.



69

movement
air

70

Air can move in ______ direction.
WIND is really a movement of _____.
Air contains __________ which is part of the Fire Triangle.

101

(a) 30%
(b) wet

102

FOREST FUEL FACTORS

Let us now consider FOREST FUELS.

FOREST FUEL FACTORS

1. Size of Fuels
2. Arrangement
3. Volume

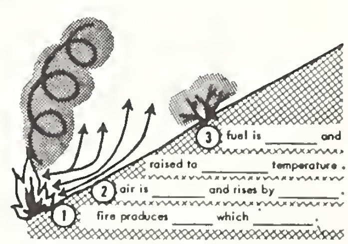
GO TO NEXT FRAME

133

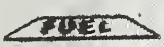
(1) Heat from fire rises and heats the fuel just above by convection to ignition temperature.
(2) Radiation is greater.

134

Fill in the events on the diagram starting with (1)



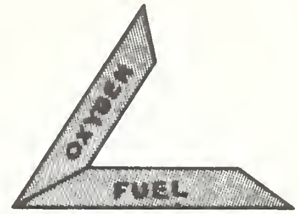
6



(any other reply is incorrect)

7

In addition to FUEL, to have combustion we must also have oxygen. The FUEL will burn only if oxygen is present.



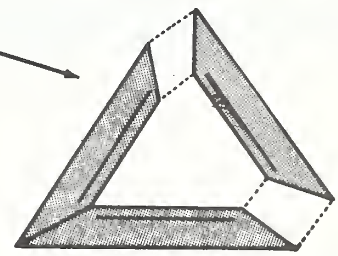
GO TO NEXT FRAME

38

A
heat

39

(a) complete this FIRE TRIANGLE.
(b) the break shows that a substance must be at __________ TEMPERATURE or it will not start to combust and __________ to burn.
(c) once a substance is burning by itself, the _______ which is produced will be sufficient for the fire to continue.



70

any
air
oxygen

71

Now we see why WIND is important. It is a movement of ______, and this _____ contains __________ which supports ________________.

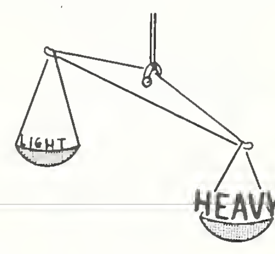
(Draw the Fire Triangle above)

102

103

(1) SIZE OF FUELS

In the Forest Service we think of SIZE OF FUELS as being →



Yes, forest fuels are either __________ or __________.

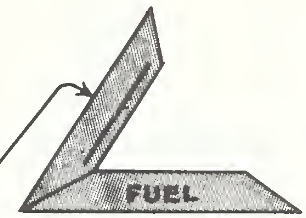
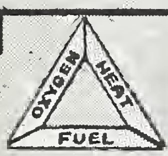
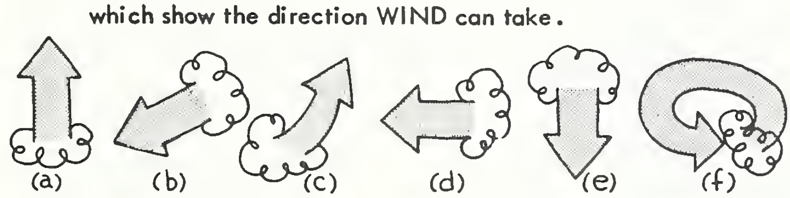
134

(1) heat, rises
(2) heated, convection
(3) heated, ignition

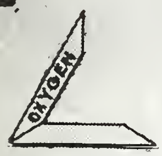
135

EXPOSURE

(a) Northern ___________ is the ______ of a hill facing to the ________.
(b) Side of a hill is often called the _________; side of a canyon is the _________.
(c) During the year, the ___________ exposure is most dangerous.

7	8
	Here is a substance which is combustible called FUEL. However, it cannot burn by itself. To burn, __________ must be present. (also print word here) 
39	**40** — SOURCES OF HEAT
(a)  (b) IGNITION continue (c) heat	There are five Main SOURCES OF HEAT that start fires. (1) Direct Application of Flame. (2) Direct Application of Embers. (3) Electrical Arcing. (4) Friction. (5) Spontaneous Combustion. We will study each of these now. GO TO NEXT FRAME
71	**72**
 air air oxygen combustion (fire, or burning)	Examine these WIND directions. Circle those which show the direction WIND can take. 
103	**104**
light heavy	A LIGHT fuel is FAST-BURNING. For example . . . . One fast-burning forest fuel is ________ leaves.  These dry LEAVES are light in weight and FAST BURNING.
135	**136**
(a) exposure, slope (or side), north (b) slope, slope (c) southwestern	STEEPNESS (a) Fire travels about _____ times faster upslope. (b) On a steep slope, fuel above a fire is __________ by the heat of the fire below.

8

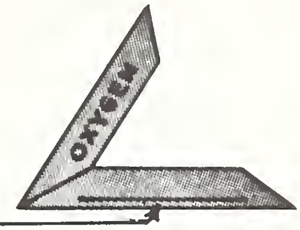


oxygen

9

And, as we have said, oxygen alone cannot produce combustion --- there must be some ________ present.

(also print it here)

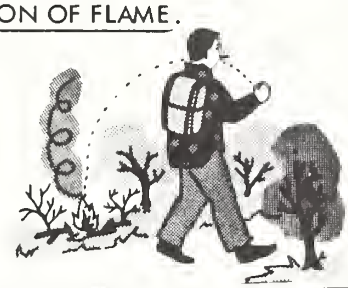


40

41

We will first discuss DIRECT APPLICATION OF FLAME.

A lit match is an example of a DIRECT APPLICATION OF ________.



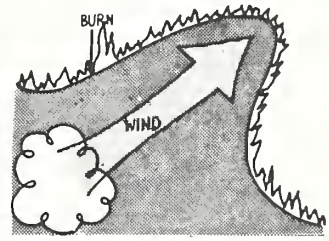
72

(a)
(b)
(c)
(d)
(e)
(f)

73

We have said that WIND brings ________ to support combustion. In addition:

(a) WIND produces a pressure due to its speed.
(b) WIND pressure can increase burning in one direction.



104

dry

105

Dry ________ are ________ in weight and ________ burning.

136

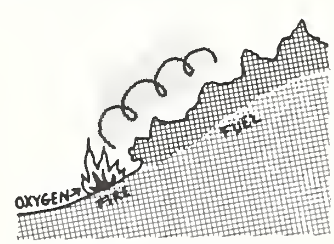
(a) 16
(b) heated

137

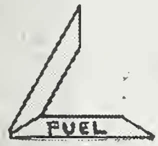
If a fire begins at the bottom of a slope, what size of burn will be produced in most cases?

(a) large (b) small (c) none

(d) not possible to say



9

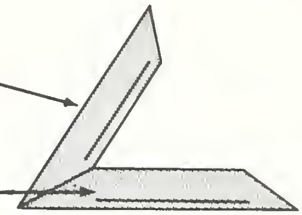


fuel

10

Yes, air contains ——————(print)——

and this supports the combustion of ——————(print)——

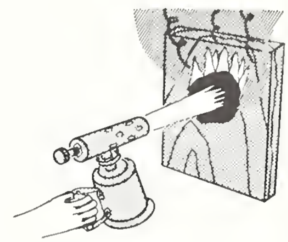


41

FLAME

42

This blowtorch indicates that one source of Heat is the Direct ______________ of ____________.

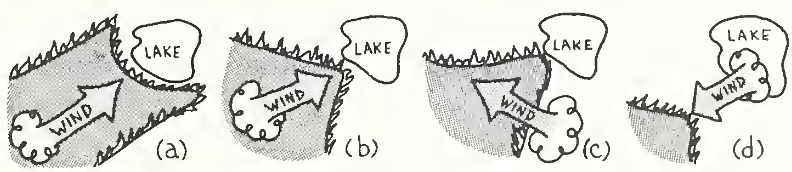


73

oxygen

74

Only one of these burns on <u>flat land</u> would be caused by the WIND as shown. Which is it?



105

leaves
light
fast

106

Which of the fuels shown are fast-burning? If you believe it is fast-burning, copy the name next to the letter.

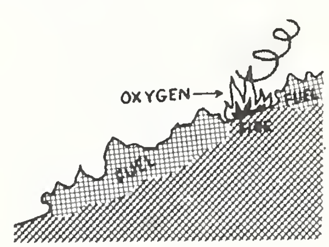
(a)____ _____ (b)_____ _____ (c) ___ ___ (d) __________

137

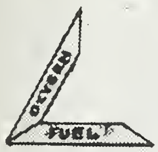
(a) large

138

If a fire begins somewhere midway on a slope, the burn will be ____________ (smaller, larger) than if it had started at the bottom.



10

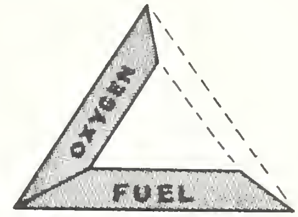


11

Fuel and oxygen alone, when combined, do not result in fire.

Something is missing.

The Fire Triangle is not complete!



GO TO NEXT FRAME

42

Application
Flame

43

Hot glowing embers, blown by the wind, can fall on some dry leaves and start a fire.

The second Source of Heat is DIRECT APPLICATION OF ________.

74

(b)

75

From this, we may depend upon ______ to control the shape of the burn.

106

(a) tree needles
(b) dry leaves
(c) dry grass

107

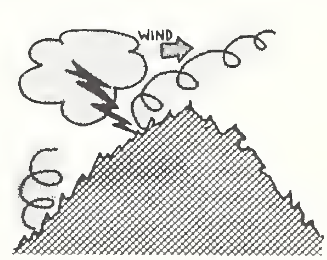
The fast-burning fuels are ______ in weight and cause a rapid spread of ______. They also create heat to raise the IGNITION TEMPERATURE of HEAVY fuels.

138

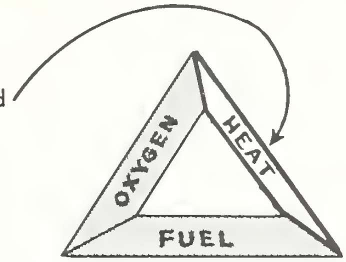
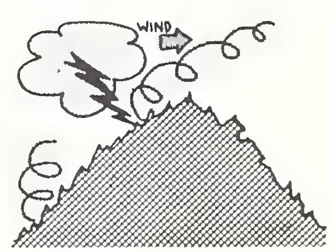
smaller

139

During the thunderstorm shown, a fire is started due to ________ ________ near the top of a steep slope. Within a short time, a second fire is observed near the bottom of the slope.



725-565 O-64—4

11	12
	The Fire Triangle is complete when we add  In order for FUEL to burn, both OXYGEN and ________ have to be present.
43 EMBERS	44
	A lighted cigarette could ignite a dried out rotten log. This would be an example of a direct application of ________. 
75 wind	76
	Here is the wind . . . . and here is the fire . .  Under normal conditions, where do you believe the sparks and embers would land? CIRCLE one or more letters. A B C D E
107 light fire	108
	HEAVY fuels are ususally not fast-burning. HEAVY fuels are ________ burning. Once a HEAVY fuel is burning, it ignites ________ and produces a great amount of heat.
139 electrical arcing	140
	The second fire observed near the bottom of the slope can best be explained by: (a) a second bolt has hit at the bottom. (b) sparks and embers are carried to the bottom by spotting. (c) burning logs and cones roll to the bottom. (d) spontaneous heating. (e) conduction. 

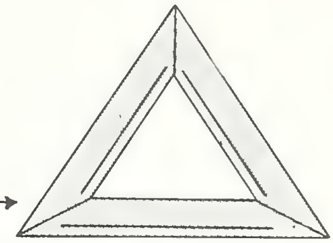
12

HEAT

13

Combustion occurs only when the Fire Triangle is complete.

Complete all three parts of this FIRE TRIANGLE. ——————(print)————→



44

embers

45

In this forest scene, the rider is flicking live cigar ashes onto quick-burning fuel. This illustrates the DIRECT ____________ OF _________ .

76

You should have circled all the letters. Ⓐ Ⓑ Ⓒ Ⓓ and Ⓔ.

77

The condition when WIND causes sparks and embers to be blown ahead of the main fire into unburned fuel is called spotting. Such new fires are spot fires.

GO TO NEXT FRAME

108

slow
slowly

109

Which of the fuels shown are slow-burning? If you believe it is slow-burning, copy the name next to the letter.

(a) _________ (b) ____ ____ (c) _________ (d) ____ ____

140

(c) burning logs and cones roll to the bottom.

141

Let's concentrate now on hill and canyon fire behavior, since the Forest Service is responsible for many large areas which are not flat or built-up with man-made structures.

Fires burn about _____ times faster upslope than down.

13

14

The Fire Triangle consists of FUEL, OXYGEN and HEAT. Cambustion is produced when all three are present. After the fire has started, fram where daes the additianal HEAT came? Select ane answer fram thase shawn.

CIRCLE THE LETTER WHICH YOU BELIEVE BEST ANSWERS THE QUESTION:

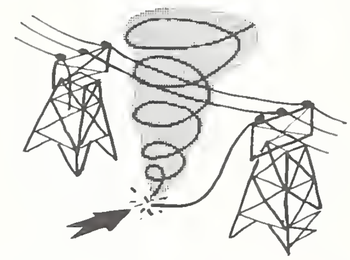
a. heat cames fram surrounding atmasphere.
b. heat cames fram the fire itself.
c. heat cames fram same autside saurce.
d. heat cames fram the oxygen.
e. nane af these.

45

APPLICATION
EMBERS

46

The third SOURCE OF HEAT can accur when a high tensian pawer line has snapped and is dangling an the graund. This demanstrates fire caused by ________________ ARCING.



77

78

If WIND blaws sparks ahead ta areas af unburned ________, then it is likely that small ______ fires will start.

109

(a) log
(b) stumps
(d) large limbs

110

FOREST FUELS

(a) Light fuels are ______-burning. A lag is an example af a ______-burning fuel.
(b) Slaw-burning fuels praduce ________ amaunts af _________ during cambustian.
(c) Dry leaves are ______-burning and are _________ fuel.
(d) Large limbs are ______-burning and are _________ fuel.

141

16

142

The actual speed af fire an a slope will depend upan the SIZE af fuel: ________ fuel will burn faster than _________ fuel. It will alsa depend upan CONTINUITY: fuel which is patchy will burn mare ________ than fuel which is __________.

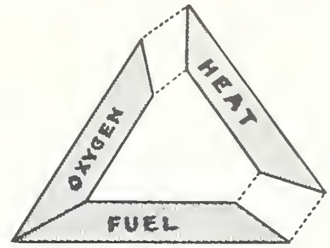
14

the most correct answer is

(b) heat comes from the fire itself.

15

Fire results from the proper combination of FUEL + OXYGEN + HEAT. By breaking the Fire Triangle, we can stop combustion. One way to do this is to reduce HEAT.



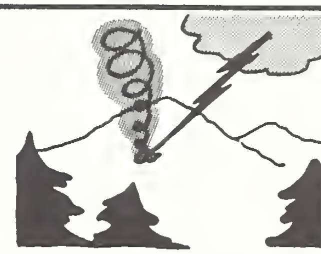
GO TO NEXT FRAME

46

ELECTRICAL

47

We often think of electric-powered equipment in connection with electrical arcing. However, LIGHTNING produces heat and causes many fires.



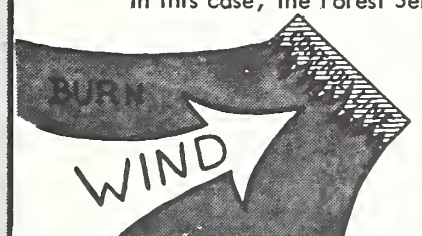
Lightning is a form of ____________ energy and it produces heat and causes __________

78

fuel
spot

79

In this case, the Forest Service has established the control line shown.



Suddenly a WIND increases over the burn. Write what you believe could happen.

____

____

____

____

110

(a) fast, slow
(b) large, heat
(c) fast, light
(d) slow, heavy

111

So far we have talked about the speed that forest fuels burn.

Light fuels burn ______ while heavy fuels burn ________.

142

light
heavy
slowly
uniform

143

In addition to SIZE and CONTINUITY of fuel, we must also consider the COMPACTNESS. If the fuel is ________ arranged it will have a small amount of ________ mixed with it, but if it is ________ arranged, then much more ________ will be available for rapid burning.

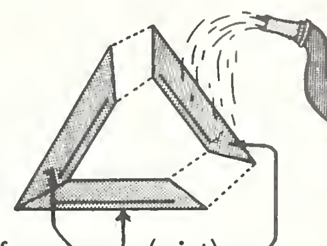
15	16 To reduce HEAT, the Forest Service often uses a liquid which is available in most places and is used for washing and drinking. __________ is used on fires to reduce the HEAT. 
47 electrical fires	48 So far we have discussed three SOURCES OF HEAT; (1) direct application of __________, (2) direct application of __________ and (3) ______________ arcing. The fourth is heat caused by FRICTION. Moving machinery which is not lubricated or properly cooled will produce heat.
79 Sparks and embers jump over the control line causing spotting and spot fires.	80 WIND can cause embers to produce ______ fires. When the control line is jumped by these fires, then ___________ has occurred.
111 fast slowly	112 (2) ARRANGEMENT The second FOREST FUEL FACTOR that we will consider is the ARRANGEMENT of the fuel. By arrangement we mean: 1. GROUND OR AERIAL . . . 2. CONTINUITY . . . 3. COMPACTNESS GO TO NEXT FRAME
143 tightly oxygen loosely oxygen	144 Also, the position will have some control over the speed of the fire. Ground fuels will burn ________ than ________ fuels which have a greater oxygen supply.

16

water

17

One way to reduce HEAT and break the Fire Triangle is by applying water. The effect of water is to COOL the fuel and lower its temperature. The diagram illustrates reduction of heat by the process of ________. The FIRE TRIANGLE consists of ——(print)

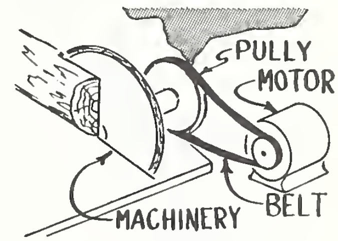


48

flame
embers
electrical

49

Suppose that a belt drive is used to run a piece of machinery. The belt slips on the pulley. Heat is produced due to ________ and a fire can be the result.



80

spot
spotting

81

The Forest Service halts a fire along a ________ line. However, if a ______ comes up suddenly over the burn, it is possible for ______ and ________ to be blown over the ________ line causing ________. This produces ______ fires.

112

113

ARRANGEMENT (1. Ground or Aerial)

Fuel on the ground is called GROUND fuel.

GROUND fuel does not have much movement of air around and through it.

GO TO NEXT FRAME

144

slower
aerial

145

Use your pencil and, below the heavy line, CIRCLE the words which stand for high-speed, up-slope fires.

POSITION	SIZE	CONTINUITY	COMPACTNESS	VOLUME
Ground	Light	Patchy	Tightly Arranged	Large
Aerial	Heavy	Uniform	Loosely Arranged	Small

17

cooling

18

CIRCLE ONE

Heat can be reduced by cooling with water. How would OXYGEN be removed?

(a) applying dirt.
(b) cooling with water.
(c) closing the valve and thereby removing the fuel.
(d) none of these.

49

friction

50 The fifth SOURCE OF HEAT is Spontaneous Combustion.

The dictionary defines this as "coming from within, or self-acting". In this pail of oily rags, we see some paper and wisps of smoke. The oil, cloth and paper have combined with oxygen in the air to produce combustion which caused the fire and smoke. We call this ________________ combustion.

81

control
wind
sparks
embers
control
spotting
spot

82

In our study of WEATHER FACTORS we have seen the effect of WIND.

We will now study the effect of TEMPERATURE.

GO TO NEXT FRAME

113

114

Fuel in the air is called AERIAL fuel.

AERIAL fuel does allow air to circulate around and through it.

Air contains ____________.

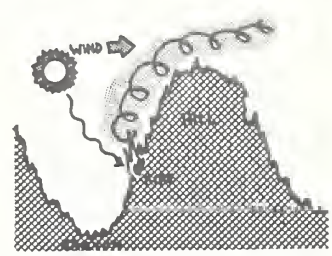
145

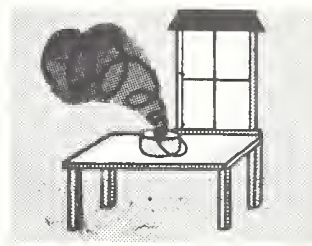
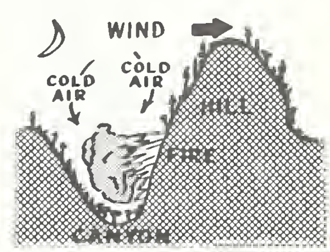
Aerial
Light
Uniform
Loosely Arranged
Large

146

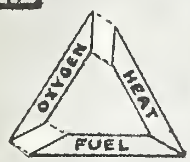
CANYON FIRE BEHAVIOR

During the day, the heated air and smoke will ______ in this fire, and oxygen will feed the fire from _________(above, below).



18	19
(a) applying dirt.	Draw the FIRE TRIANGLE here → to illustrate that APPLYING DIRT can break the triangle. Be careful to select the proper side to be broken.
50 spontaneous	51 If a chemical is on a table by itself and the sunlight causes a chemical reaction, the resulting fire was produced by ______________ combustion. 
82	83 To study temperature in "weather factors" we must briefly review IGNITION TEMPERATURE. A substance is at IGNITION TEMPERATURE when it starts to _____ and continues without any _____ from ___________ source.
114 oxygen	115 Air contains OXYGEN. Which fuel will have more oxygen around it? (a) ground (b) aerial (c) can't tell
146 rise below (or beneath)	147 During the night, as the land cools, cold air will descend into the canyon along the slopes. The fire will change direction and go ______ slope into the _______. 

19



(any other diagram is incorrect)

20

If OXYGEN can be removed by applying dirt, then what can be done with FUEL to break the Fire Triangle?

CIRCLE THE MOST CORRECT ONE

(a) cooling with water.
(b) closing the valve of a gas line and thereby removing the fuel.
(c) clearing with a bulldozer.
(d) two of these are correct.

51

spontaneous

52

Combustion, in which heat is created from the fuel itself, is called

____________ ____________.

83

burn
heat
another

84

We must also review our old friend, the Fire Triangle.

DRAW THE FIRE TRIANGLE ⟶

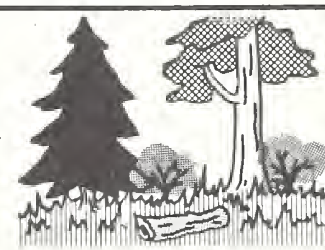
115

(b) aerial

116

ARRANGEMENT (2. Continuity)

By CONTINUITY, we mean:
is the fuel connected --- UNIFORM ⟶



. . . or is the fuel not connected ---
⟵ PATCHY

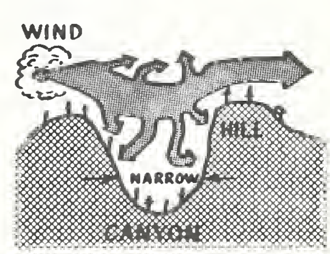
GO TO NEXT FRAME

147

down
canyon

148

A canyon is a deep valley with high, steep slopes. Here is a narrow canyon. The wind causes turbulent, or confused, drafts as it blows across this ________ canyon.



20 Answer is (d); two of these are correct.
(b) closing valve of gas line, removing the fuel.
and
(c) clearing with a bulldozer.
are correct.

21

Closing a gas valve and clearing with a bulldozer are examples of __________ the Fire Triangle by removing the _______.

Draw the triangle here ⟶ to illustrate this.

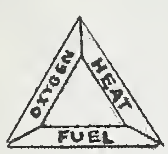
52

spontaneous combustion

53

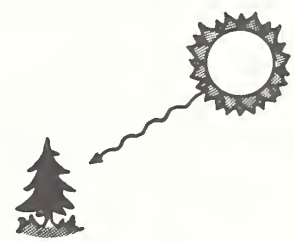
We have learned that HEAT is necessary for combustion. The Fire __________ shows this is true. We have learned that heat is produced by fuels on fire but the fuel must be hot enough to burn by itself --- it must be at __________ temperature. Finally, we just learned there are five sources of ________.

84



85

The weather can make it easier for fires to start. The sun can heat the fuel and __________ its temperature. This is heat transfer by __________.



116

117

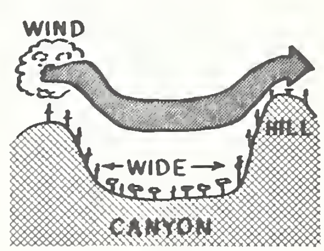
If the fuel is connected it is ____________ while if it is spread out and ______ connected it is patchy.

148

narrow

149

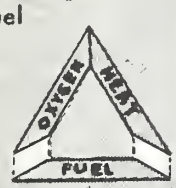
Here is a wide canyon. Notice that the wind across it normally is steady and the violent up and down drafts are absent.



GO TO NEXT FRAME

21

breaking
fuel



22

Combustion may be stopped by:

(a) __________ the HEAT; __________ is often used for this.
(b) __________ the FUEL; in a forest area this is sometimes accomplished by using a __________.
(c) __________ the OXYGEN; in a mountain area this consists of __________ dirt.

53

Triangle
ignition
heat

54

Five sources of HEAT that cause fires are:

(1) ____________________
(2) ____________________
(3) ____________________
(4) ____________________
(5) ____________________

85

increase (or raise)
radiation

86

The sun or a hot wind can __________ the forest fuel and cause its __________ to increase.

117

uniform
not

118

The continuity of this fuel ⇨

is __________.

149

150

Air currents in a canyon are similar to water currents in a river. Here is a diagram of currents in a river. Notice the whirlpools near the sides as the water becomes turbulent and confused.

GO TO NEXT FRAME

22

(a) reducing; water
(b) removing; bulldozer
(c) removing; applying

23

IGNITION TEMPERATURE

We are now ready to discuss IGNITION TEMPERATURE. IGNITION TEMPERATURE is the temperature of a substance at which it will ignite and burn.

Every substance has an IGNITION ____________.
At this ____________ the substance will burn.

54

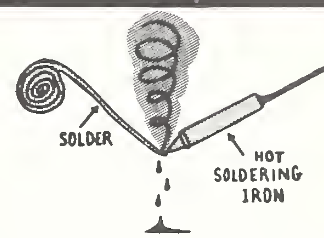
(1) Direct Application of Flame.
(2) Direct Application of Embers.
(3) Electrical Arcing.
(4) Friction.
(5) Spontaneous Combustion.

55

HEAT TRANSFER

Let us examine HEAT TRANSFER, now.

HEAT is a form of energy which can be moved or transferred from one substance to another. In this example, a hot iron is transferring HEAT to cold solder. The solder is heated and it melts.



GO TO NEXT FRAME

86

heat
temperature

87

When a WIND blows across forest areas, the fuel becomes dried-out. The wind actually causes the moisture in the fuel to leave by evaporation.

GO TO NEXT FRAME

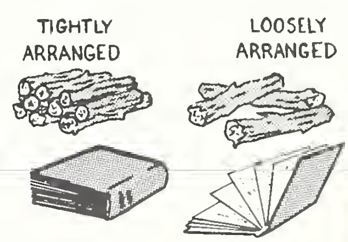
118

uniform

119

ARRANGEMENT (3. Compactness)

The COMPACTNESS of a fuel refers to whether it is TIGHTLY ARRANGED and has little oxygen in with it, or LOOSELY ARRANGED with a large amount of oxygen mixed with it.



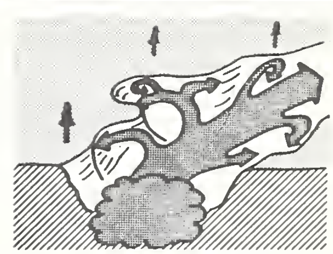
GO TO NEXT FRAME

150

151

And here is a canyon of the same shape. Wind blowing along, through it, produces turbulent currents and confused drafts.

Think what this can do if a fire starts on a slope!



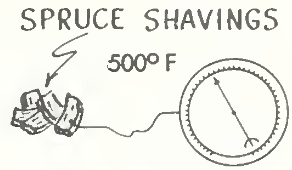
GO TO NEXT FRAME

23

TEMPERATURE
temperature

24

Spruce shavings ignite at 500° F. This is the __________ TEMPERATURE of spruce shavings.



55

56

HEAT is TRANSFERRED in three ways:

1. Radiation

2. Convection

3. Conduction

GO TO NEXT FRAME

87

88

Sun will ______ forest fuel and ______ its temperature. Hot wind will remove ________ from the forest fuel. Together, these will bring the fuel temperature ______ to its IGNITION TEMPERATURE.

119

120

Loosely arranged fuel has a ________ amount of __________ mixed with it. It therefore burns __________. It is not as COMPACT as tightly arranged fuel. Tightly arranged fuel has a ________ amount of __________ mixed in with it.

151

152

If wind blows across a narrow canyon, the currents will be __________. The same wind across a wide canyon will be calmer.

24

IGNITION

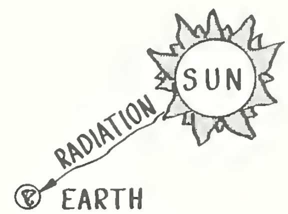
25

The IGNITION TEMPERATURE is the temperature of a substance when it just starts to ________.

56

57

The sun is hot and the HEAT which leaves the sun travels to the earth. It heats the earth. This is an example of RADIATION.



GO TO NEXT FRAME

88

heat
increase (or raise)
moisture
close (or up)

89

We have said many times that the Fire Triangle consists of ____________, ____________, and __________. Air contains ____________.

120

large
oxygen
quickly
small
oxygen

121

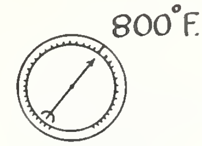
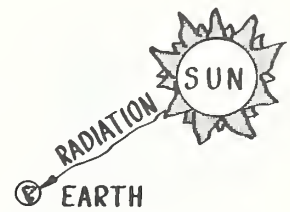
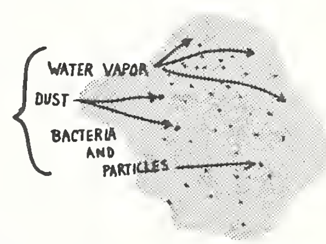
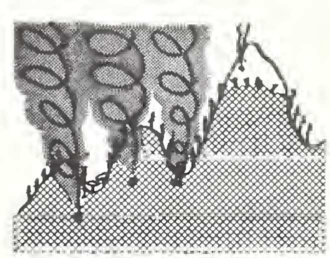
Fuel with large air spaces between particles is called ________ ____________.

152

turbulent
(or confused)

153

If wind blows along and through a narrow canyon, the currents are similar to water currents in a __________ of the same shape. The air currents will be ________ and a fire on a slope will have large amounts of ________ fed to it and probably produce sparks and then ______ fires.

25 burn	26 Look at the thermometer. It reads ______. This is spoken as "800 degrees Fahrenheit". The abbreviation for degrees is ____, and for Fahrenheit it is____. 
57	58 In radiation, the hot substance does not have to be in direct contact with the cold substance. The heat is transferred through the air. Heat which is transferred through the air from one substance to another is an example of __________. 
89 fuel oxygen heat oxygen	90 Air contains oxygen and it also contains  We will be studying the WATER VAPOR in air. GO TO NEXT FRAME
121 loosely arranged	122 Loosely arranged fuel is ______ compact than ___________ ___________ fuel.
153 river turbulent oxygen spot	154 Electrical arcing at high elevations results from storms and the ________ they produce. This is almost always followed by thunder. 

26

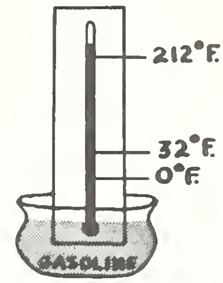
800° F
(if F is left out, the answer is incorrect)

o
F

27

Regular gasoline has an IGNITION TEMPERATURE of about 700° ______________ .
(spell out)

The FUEL in this illustration is not at its __________ __________
and therefore will not __________
even though both HEAT and __________ are present.



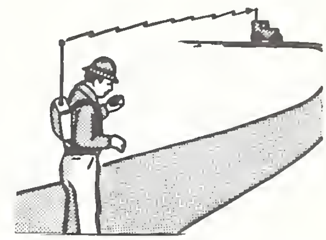
58

radiation

59

In the Forest Service, two-way radio is used to communicate. Radio energy is transferred through the air from one radio unit to another.

Radiation of HEAT is transferred through the ______ from one substance to __________ .



90

91

WATER VAPOR is invisible in the air. WATER VAPOR is moisture in the air which is around us.

Can we see water vapor in the air? ______ (Yes, No)

122

less
tightly arranged

123

(3) VOLUME

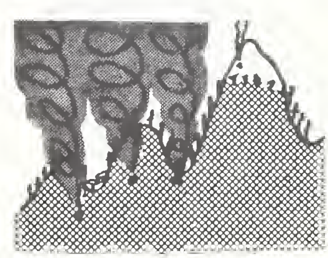
Finally, we come to the third Forest Fuel Factor, the VOLUME of forest fuel. You recall that once a fire begins, it produces its own ______ so combustion may continue. Therefore, more fuel is used, more oxygen is used, more heat is produced, and so on! If a large VOLUME of fuel is available, the fire will __________ in size.

154

lightning

155

At very high elevations, more fires are caused by these storms and the __________ they produce than by anything else.



27

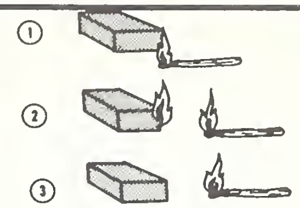
Fahrenheit
IGNITION
TEMPERATURE
burn
OXYGEN

28

(1) A FUEL is raised in temperature by applying HEAT.

(2) As soon as it starts to burn, the HEAT is removed.

(3) With HEAT removed, the fire goes out.



The FUEL was not really at IGNITION TEMPERATURE. It must continue to burn using its own HEAT to be at IGNITION TEMPERATURE.

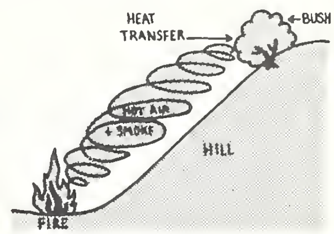
GO TO NEXT FRAME

59

air
another

60

The second way that HEAT may also be TRANSFERRED is by convection. In this diagram we see the movement of hot air and smoke from the fire rising along the hill. The hot air heats the bush. This is an example of heat transfer by convection.



GO TO NEXT FRAME

91

No

92

The meter is measuring a "moist" air, but notice it is not "wet" air.

Water vapor is ____________ in the air. The amount will change from day-to-day.

The meter

123

heat
increase

124

Now, combine all of these ideas on FOREST FUELS to complete this: When we talk of fast-burning fuel we also mean ________ fuel. If fuel is connected continuously it is ____________, while if it is separated it is __________. A compact fuel is called __________ ____________ because it has very little __________ mixed with it. If a large __________ of fuel is available, the fire will enlarge.

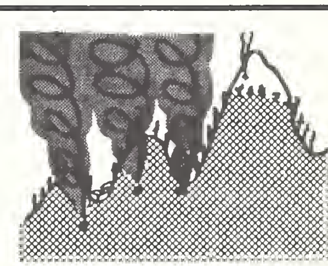
155

lightning

156

At very high elevations, smaller fires usually occur because:

(a) fuel is uniform.
(b) fuels there are less likely to combust because they hold moisture.
(c) not true -- larger fires occur.
(d) none of the above.



28

29

IGNITION TEMPERATURE is when FUEL ________ and continues to ________ without adding ______ from an outside source.

60

61

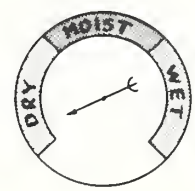
If air is warm and it moves to another location --- then gives off some heat to the surrounding area, this is heating by ______________.

92

moisture

93

Air which has little water vapor has a low ____________ content. It is dry air.



124

light
uniform
patchy
tightly arranged
oxygen
volume

125

TOPOGRAPHY

The last topic in this INTRODUCTION TO THE FUNDAMENTALS OF FIRE BEHAVIOR will deal with the physical features of the earth's surface . . . this is known as topography. This is easy to remember since it refers to the "top of" the earth --- topo-graphy = topography.

GO TO NEXT FRAME

156

(b)

157

VERY HIGH ELEVATION

(a) The size of fires at very high elevations is ________. This is due to the ______ which holds its __________.

(b) The main cause of fire at very high elevations is ________________.

29

burns
burn
heat

30

From the chart, what can you conclude about the IGNITION TEMPERATURES of different FUELS? (write) ______________
____
____
____

FUEL	IGNITION TEMPERATURE *
Woolen Blanket (roll)	400° F
Short-Leaf Pine (shavings)	440° F
Spruce (shavings)	500° F

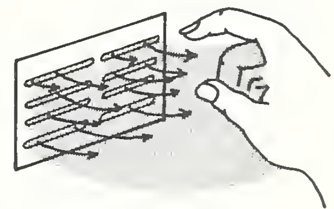
(* approximate)

61

convection

62

The hot air heater you see is transferring heat by ______________.

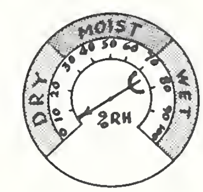


93

water (or moisture)

94

The measuring of the amount of water vapor in the air is called finding the relative humidity. It is in % (PERCENT).

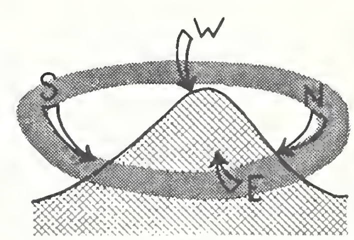


GO TO NEXT FRAME

125

126

Here is a hill. The side of the hill facing the south is called the southern exposure. Therefore, the side facing the north is called the ______________ exposure, the side facing east is the ______________ exposure, and the side facing west is the ______________ exposure.



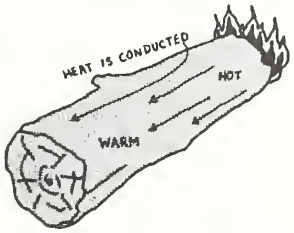
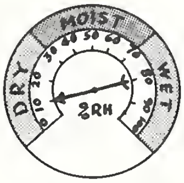
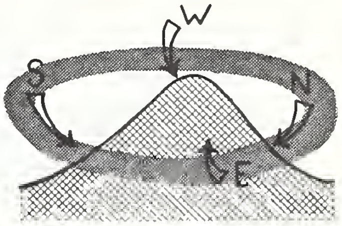
157

(a) small, fuel, moisture
(c) lightning (or electrical arcing)

158

Well, sir, you have just completed

"INTRODUCTION TO THE FUNDAMENTALS OF FIRE BEHAVIOR"

30 fuels have different ignition temperatures (or) ignition temperatures of fuels are not the same.	31 Pine shavings and spruce shavings will ignite at _______________ (same, different) temperatures.
62 convection	63 Fire at the end of this log produces heat. Some of it is conducted inside the log in this direction. Heat is transferred by __________________. 
94	95 If the relative humidity is 10% as shown, the air is _____ and has very little _______ vapor or moisture. 
126 northern eastern western	127 The western ___________ is the side of the hill facing ______. 

31

different

32

Woody fuels of the forest have different __________ temperatures.

GO TO FRAME 33, PAGE 1

63

conduction

64

HEAT TRANSFER:

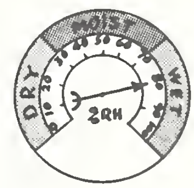
(a) from a far-away object, such as from the sun, is transfer by ____________.
(b) due to a heated substance moving, such as heated air, is by ____________.
(c) inside an object, such as from the hot end of a log to the cool end, is by ____________.

95

dry
water

96

If the relative humidity is 80%, the air is ________ and has considerable __________.



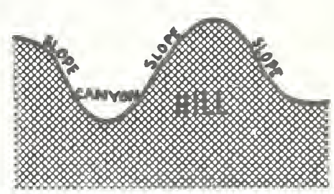
127

exposure
west

128

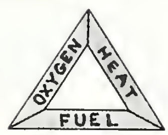
A common term for "side" of a hill or of a canyon is SLOPE.

A SLOPE is the ______ of a hill. The side of a canyon is also the ________.



SUMMARIZED REFERENCE

1. THE FIRE TRIANGLE



The act of burning is called COMBUSTION.

In order to have combustion, FUEL, OXYGEN and HEAT are needed.

Needed for Combustion	Breaking the Fire Triangle
Fuel	Constructing a fire line
Oxygen	Apply dirt
Heat	Cool by applying water

2. IGNITION TEMPERATURE

The IGNITION TEMPERATURE is the temperature of a substance at which it will ignite and continue to burn without adding heat from an outside source.

Different fuels have different ignition temperatures.

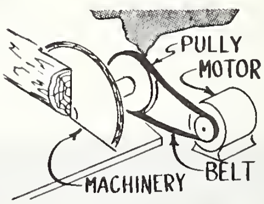
3. SOURCES OF HEAT

(1) Direct Application of Flame
(matches, blowtorch)

(2) Direct Application of Embers
(lighted cigarette, cigar ashes)

(3) Electrical Arcing
(snapped high tension power line, lightning)

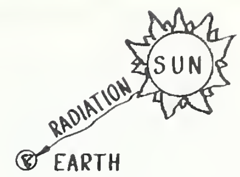
(4) Friction
(slipping pulley on machinery, moving machinery)



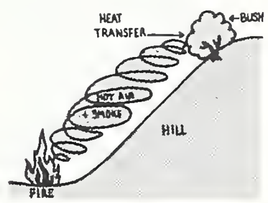
(5) Spontaneous Combustion
(pail of oily rags)

4. HEAT TRANSFER

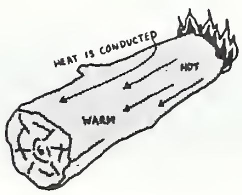
(1) Radiation
Heat is transferred from its source, through the air, to an object.



(2) Convection
Heat is transferred by the movement of hot air and smoke rising and heating the fuel above.



(3) Conduction
Heat is transferred within the fuel, or from one fuel to another, by direct contact (from the hot point to the cold point).



5. WEATHER FACTORS

(1) Wind

Wind is a movement of air. This air contains oxygen which supports combustion.

Wind pressure can increase burning in one direction or another.

Wind can blow sparks and embers ahead of the main fire into unburned fuel. This is called SPOTTING. Such new fires are called spot fires.

(2) Temperature

The sun or a hot wind can heat the forest fuel and cause its temperature to increase. As the fuel temperature approaches the ignition temperature, less heat is required to start a fire.

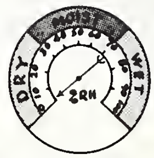
(3) Humidity

Humidity is moisture.

Relative humidity is the amount of moisture in the air.

Moisture in the air is called Water Vapor.

The measuring of the amount of water vapor in the air is called finding the relative humidity. It is in % (PERCENT).



Wind blowing across forest areas will dry out the forest fuel by causing the moisture in the fuel to leave by evaporation. This makes the forest fuel more susceptible to burning.

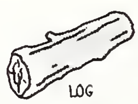
6. FOREST FUEL FACTORS

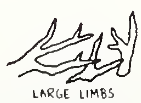
(1) Size of Fuel

In the Forest Service we think of size of Fuel as being light or heavy.

a. Light fuel is fast burning.
(examples: dry leaves, dry grass, tree needles)

b. Heavy fuel is slow burning.
(examples: logs, tree stumps, large limbs)





(2) Arrangement

The arrangement of fuel also determines how fast the fuel will burn due to the oxygen in the air around it. The more oxygen around the fuel, the faster it will burn.

a. Ground or Aerial

1 Ground fuel will burn slower. (less air around it)

2 Aerial fuel will burn faster. (more air around it)

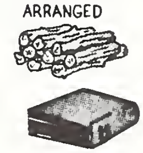
b. Continuity - by continuity we mean, is the fuel:

1 Uniform (fuel connected) - fast burning.

2 Patchy (fuel not connected) - slow burning.

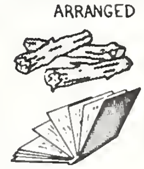
c. Compactness - by compactness we mean, is the fuel:

TIGHTLY ARRANGED



1 Tightly arranged - slow burning.

LOOSELY ARRANGED



2 Loosely arranged - fast burning.

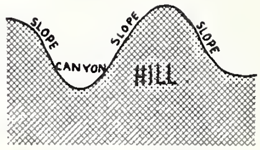
(3) Volume

With a large amount of fuel available, the fire will burn with large amounts of heat.

7. TOPOGRAPHY

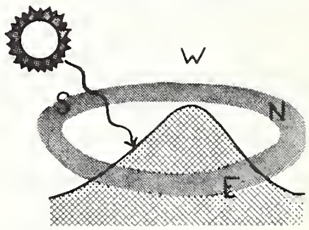
Topography deals with the physical features of the earth's surface.

SLOPE – is the "side" of a hill or canyon.



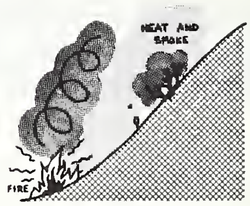
(1) <u>Exposure</u>

The southwest exposures receive most of the sun during the year. It is the most hazardous exposure, since it also receives the most heat.



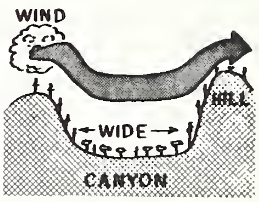
(2) <u>Steepness</u>

On a steep slope, fires burn about 16 times faster upslope than down.

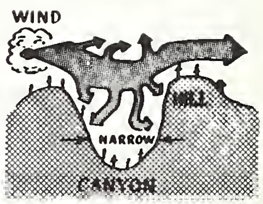


(3) <u>Canyon fire behavior</u>

Wind across a <u>wide</u> canyon is normally steady and the <u>violent</u> up and down drafts are absent.



Wind across a <u>narrow</u> canyon causes turbulent, or <u>confused</u>, drafts.

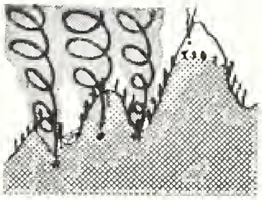


If wind blows along and through a narrow canyon, the currents are similar to water currents in a river of the same shape. The air currents will be turbulent and a fire on a slope will have large amounts of oxygen fed to it and probably produce sparks and then spot fires.

(4) Very High Elevation

The main cause of fire at very high elevation is lightning.

Usually the size of fires at very high elevations is small. This is due to the fuel which holds its moisture.



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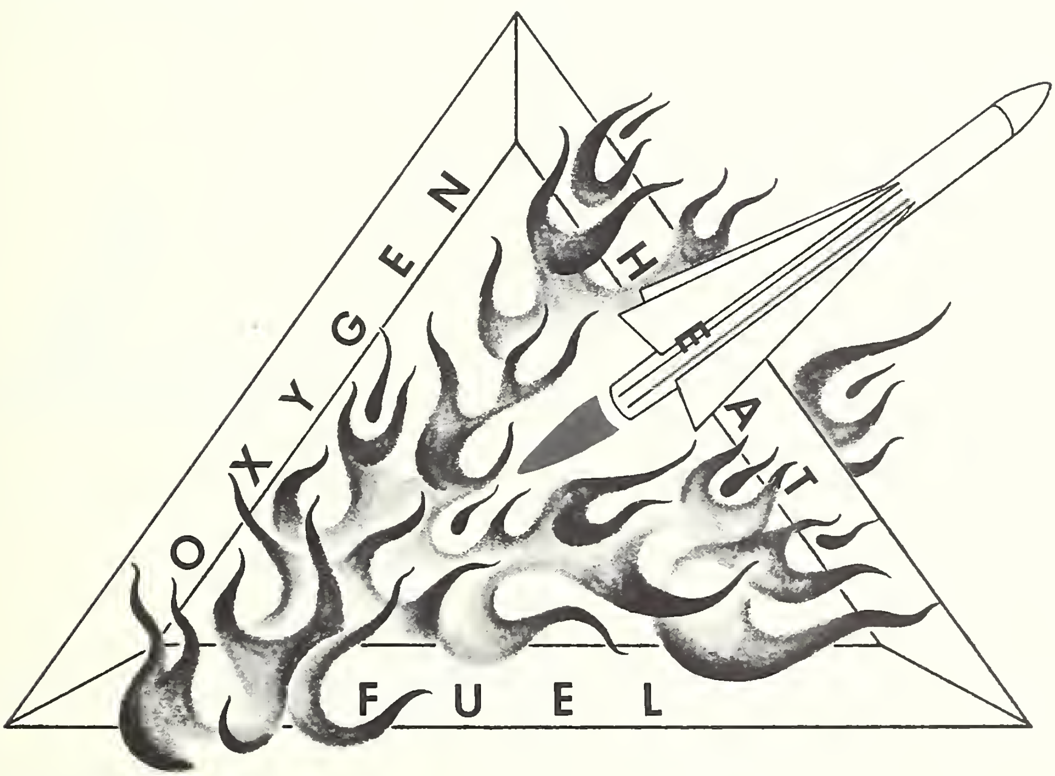
INTRODUCTION TO THE FUNDAMENTALS OF FIRE BEHAVIOR

Answer Seperate For Use With Programmed Text



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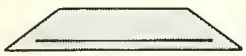
ANSWER SHEET 1

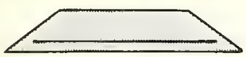
1. GO TO NEXT FRAME

2. ____________________

3. ____________________
____
____

4. ____________________

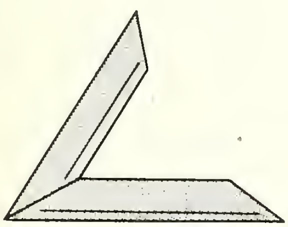
5. 

6. 

7. GO TO NEXT FRAME

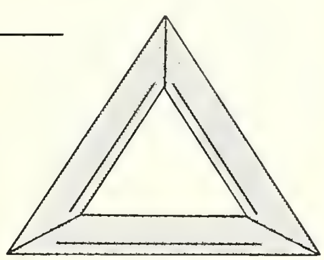
8. ____________________

9. ____________________

10. 

11. GO TO NEXT FRAME

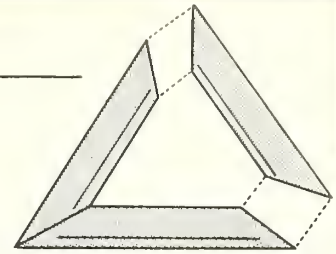
12. ____________________

13. 

14. ______________________________________

15. GO TO NEXT FRAME

16. ____________________

17. ____________________ 

18. ____________________

19.

20. ______________________________________

21. ____________________
____

22. (a)____________________ ____________________
(b)____________________ ____________________
(c)____________________ ____________________

23. ____________________
____

24. ____________________

25. ____________________

26. ____________________
____
____

27. ____________________
____________________ ____________________
____
____

ANSWER SHEET 2

28. GO TO NEXT FRAME

29. ____

30. ____

31. ____

32. ____

33. (a) ____

(b) ____

34. GO TO NEXT FRAME

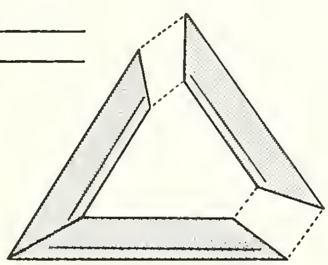
35. ____

36. ____

37. ____

38. ____

39. (a)



(b) ____

(c) ____

40. GO TO NEXT FRAME

41. ____

42. ____

43. ____

44. ____

45. ____

46. ____

47. ____

48. ____

49. ____

50. ____

51. ____

52. ____

53. ____

54. (1) ____
(2) ____
(3) ____
(4) ____
(5) ____

55. GO TO NEXT FRAME

56. GO TO NEXT FRAME

57. GO TO NEXT FRAME

58. ____

59. ____

ANSWER SHEET 3

60. GO TO NEXT FRAME

61. ____________

62. ____________

63. ____________

64. (a) ____________
(b) ____________
(c) ____________

65. B ____________
C ____________
D ____________
E ____________

66. GO TO NEXT FRAME

67. GO TO NEXT FRAME

68. ____________

69. ____________
____

70. ____________
____
____

71.

____
____
____
____

72. ________________________

73. ____________

74. ____________

75. ____________

76. ________________________

77. GO TO NEXT FRAME

78. ____________
____

79. ________________________
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____
____

80. ____________
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81. ____________
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____
____
____
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82. GO TO NEXT FRAME

83. ____________
____
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84.

85. ____________
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86. ____________
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87. GO TO NEXT FRAME

88. ____________________
____
____
____

89. ____________________
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____
____

90. GO TO NEXT FRAME

91. ____________________

92. ____________________

93. ____________________

94. GO TO NEXT FRAME

95. ____________________
____

96. ____________________
____

97. GO TO NEXT FRAME

98. ____________________
____

99. ____

100. (a)____________________
(b)____________________
(c)____________________
(d)____________________

101. (a)____________________
(b)____________________

102. GO TO NEXT FRAME

103. ____________________
____

104. ____________________

105. ____________________
____
____

106. ____

107. ____________________
____

108. ____________________
____

109. (a)____________________
(b)____________________
(c)____________________
(d)____________________

110. (a)____________________ ____________________
(b)____________________ ____________________
(c)____________________ ____________________
(d)____________________ ____________________

111. ____________________
____

112. GO TO NEXT FRAME

113. GO TO NEXT FRAME

114. ____________________

115. ____________________

116. GO TO NEXT FRAME

117. ____________________
____

118. ____________________

119. GO TO NEXT FRAME

120. ____________________
____
____
____
____

121. ________________ ____________________

122. ____________________
________________ ____________________

123. ____________________
____

124. ____________________
____
____
____________________ ________________
____
____

125. GO TO NEXT FRAME

126. ____________________
____
____

127. ____________________
____

128. ____________________
____

129. ____________________

130. ____________________

131. ____________________

132. GO TO NEXT FRAME

133. (1)____________________________________
____
(2)____________________________________
____

134. (1)______________ __________________
(2)______________ __________________
(3)______________ __________________

135. (a)__________________
____
____
(b)__________________
____
(c)__________________
____

136. (a)__________________
(b)__________________

137. ____________________

138. ____________________

139. ____________________ ______________

140. ____________________________________

141. ____________________

142. ____________________
____
____
____

143. ____________________
____
____
____

144. ____________________
____

145. Ground Light Patchy Large
Aerial Heavy Uniform Small
Tightly Arranged Loosely Arranged

146. ____________________
____

147. ____________________
____

148. ____________________

149. GO TO NEXT FRAME

150. GO TO NEXT FRAME

151. GO TO NEXT FRAME

152. ____________________

153. ____________________
____
____
____

154. ____________________

155. ____________________

156. ____________________

157. (a)____________________
____

(b)____________________

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